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Effect of Tillage Systems on the Variability of Soil-Water Tensions and Soil-Water Content

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ABSTRACT

Field experiments were conducted on a Webster silty clay loam soil to study the effect of four different tillage systems (no-till, chisel plow, paraplow and moldboard plow) on soil-water tension and soil-water content. Data on soil-water tensions were collected by using tensiometers installed at 0.15, 0.3, 0.6, 0.9 and 1.5 m depths within the crop row. A portable pressure transducer equipped with a syringe needle and a digital pressure indicator was used to indicate soil-water tensions. Field data on soil-water tensions and volumetric soil-water contents for various tillage systems were collected during the 1983 and 1984 growing season.

The results of this study indicated that tillage systems affected the soil-water tensions in the surface layer (0 to 0.3 m) of the soil in 1984, but the differences were not statistically significant at the 5% level in 1983. Results showed that the variability (standard deviation and range) of soil-water tensions increased when the soil became drier under all tillage systems, but the variability began to decrease at about 45 kPa of soil-water tension and continued to decrease further at higher values of soil-water tensions (reaching up to 80 kPa).

INTRODUCTION

Measurement of soil-water properties such as soil-water tension and hydraulic conductivity is necessary to meet the data input needs of hydrologic modeling. The relationships between the soil properties and soil-water content must also be known to determine the available water for plants and to model the movements of water and solutes through the soil profile. But the variability and heterogeneity of most field soils make both water and solute movement studies very complicated. Therefore, reliable estimates of field measured soil-water properties are needed to have some degree of confidence in the predictions made by the hydrologic models.

Conservation tillage practices have become widely accepted in most parts of the country. Research has clearly shown that with increasing crop residue cover, significant soil loss reductions can be achieved (Laflen and Colvin, 1981). Conservation tillage systems not only reduce soil erosion and downstream pollution but also have the potential to generate higher economic returns and better management of soil-water systems on some soils. Currently, conservation tillage systems are the focus of much needed research for producing higher crop yields and preserving soil and water resources for future generations. Kramer and Alberts (1988) reported the results of a six-year study of three tillage systems (moldboard plow, chisel plow and no-till). They found that tillage systems had no significant effect on plant population and grain yield. Chaplin et al. (1986) found no significant effect of tillage systems (moldboard plow, chisel plow, ridge plant and no-till) on irrigated corn or soybean grain yields. Van Doren et al. (1976) reported that the yield potential of different tillage systems is site specific; researchers found that conservation tillage practices resulted in lower yields on poorly drained soils and produced higher yields on well-drained soils. Studies by Blevins et al. (1971), Jones et al. (1969) and Wittmus and Yazar (1980) reported that yield increases with conservation tillage systems were due to the increases in soil moisture in the soil profile.

Several studies have been conducted to assess the effects of tillage systems on hydraulic properties of soils (Adeoye, 1982; Blevins et al., 1983a,b; Hamblin and Tennant, 1981; Wittmus and Yazar, 1980). Allmaras et al. (1977) reported an increase in hyraulic conductivity with chisel plowing. Ehlers et al. (1980) concluded from their experiments that tillage may change soil bulk density, shoot and root growth and the water uptak pattern of a crop. Douglas and McKyes (1983) reported that the modifications of soil structure, caused by different tillage tools and their effect on hyraulic properties, can be quite complex. Amemiya (1977) has reported that even small amounts of plant residue will reduce soil losses and conserve water by increasing infiltration and reducing runoff. In a recent study by Johnson et al. (1984), investigators found that conservation tillage practices on a Griswold silt loam soil resulted in higher water contents throughout the growing season.

Reduced tillage systems seem to be excelle alternatives for reducing soil erosion and energy requirements for agricultural production. However, the effects of these tillage systems on the hydraulic and physical properties of various soils are much less clear. Therefore, it is important that we not only be able to measure but also be able to predict the effects of tillage systems on soil-water properties through hydrologic modeling. Some studies have been conducted on experimental field plots where moisture conservation was assessed indirectly by measuring increased crop production (often the main objective). However, because

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of soil variability and other factors (such as macropores in the soil profile) that can render the reasons for yield differences uncertain, it is necessary to monitor the soil-water balance in a soil profile under various tillage systems. The measurement of soil-water-retention characteristics as a function of various tillage practices and soil types is also necessary so that the effects of soil variability factors can be closely related to the crop production differences.

A field study was initiated in 1983 on a Webster silty clay loam soil at the Iowa State University Agronomy and Agricultural Engineering Research Center near Ames, Iowa, to study these relationships. The main objective of this research was to determine the effects of four conservation tillage systems no-tillage, chisel plowing, paraplowing, and moldboard plowing on soil-water tensions and soil-water contents for continuous corn production.

EXPERIMENTAL PROCEDURE

The experimental site was on a uniform Webster silty clay loam soil with a slope of less than 1% at the Iowa State University Agronomy and Agricultural Engineering Research Center near Ames, Iowa. Long-term tillage treatment plots were established in fall 1982 in the study area in a randomized complete block design with ten replications (Erbach et al., 1984). These tillage treatment plots were used for this study but with only two replications. Each plot was 27 m long and 6 m (8 corn rows) wide. The plots were planted to continuous corn with four different tillage systems (no-till, fall chisel plow, fall moldboard plow and fall paraplow). Erbach et al. (1984) used the following operations for the four systems:

- **No-till.** The plots were sprayed with a preemergence herbicide. Planting was done with a four-row John Deere 7100 planter.*
- **Fall chisal plow.** Twisted points were used to till 150 to 200 mm deep in the fall. In the spring, the plots were disked with a tandem disk or cultivated with a field cultivator to a depth of 100 mm. After disking, the plots were harrowed with a spike tooth harrow before planting. The plots then received the same treatment as the no-till plots.
- **Fall moldboard plow.** The plots were moldboard plowed in the fall to a depth of 150 to 200 mm. In the spring, the plots were either disked or cultivated to a depth of 100 mm and then harrowed before planting and herbicide application.
- **Fall paraplow.** Paraplow is a relatively recent introduction to American agriculture (Pidgeon, 1983). This implement lifts the soil at an angle with its legs and drops back a loosened soil without inverting it. Unlike chisel or moldboard plowing, most of the crop residue stays on the surface after the paraplow passes. The plots were paraplowed with either a three-leg or four-leg Howard paraplow to a depth of 300 mm in the fall. The plots were then sprayed with herbicide and planted.

*Mention of John Deere and Howard Rotavator companies does not imply endorsement or preferential treatment over others not mentioned. Trademarks are included for the benefit of the reader.

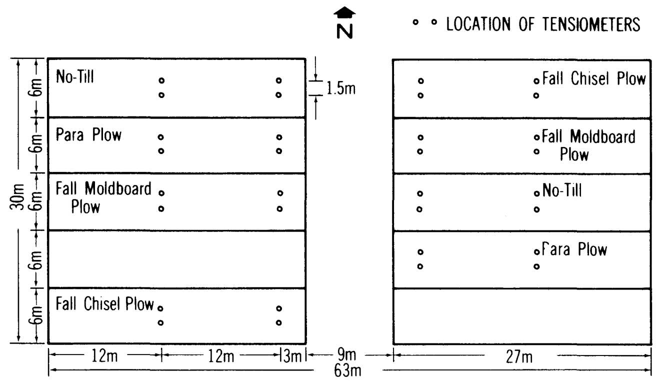

Fig. 1—Layout of experimental plots and location of the tensiometers within each plot at the Iowa State University Agronomy and Agricultural Engineering Research Center near Ames, IA.

Figure 1 shows the layout of the experimental plots used in this study.

The Webster silty clay loam soil is a naturally poorly drained soil. In this soil, water moves so slowly that the soil becomes saturated periodically during the growing season and remains wet for long periods if not artificially drained. The experimental area had an established subsurface drainage system to remove excess water. Table 1 gives some physical properties of the Webster soil. The experimental data on soil-water tensions were collected by using relatively low-cost tensiometers constructed of 12.7 mm-diameter PVC pipe with short sections of clear plastic tubing at the upper end and one-bar, porous ceramic cups at the lower end. A septum rubber stopper was used to close off the clear plastic tubing and make an airtight seal. The average cost of this type of tensiometer was just over five dollars. Marthaler et al. (1983) have given the details of this type of tensiometer. A portable pressure transducer consisting of a syringe needle attached to a pressure transducer and a digital pressure indicator was used to measure tensions.

An array of 20 tensiometers was installed in each tillage treatment plot at four locations and at depths of 0.15, 0.3, 0.6, 0.9 and 1.5 m in the rows. Figure 1 gives the location of tensiometers in each plot. Tensiometer readings wre generally taken three times a week during the growing season (May through October). Soil samples were also taken from five depths (0.15, 0.3, 0.6, 0.9 and 1.5 m) and at four locations close to the tensiometers from each of the tillage plots for monitoring *in situ* profile volumetric water content. The soil samples were taken from the same hole, with hand-driven probes

TABLE 1. Selected Physical Properties of the Webster Silty Clay Soil

	Particle Size, mm					
Depth, m	Sand 2-0.05 mm	Coarse Silt 50-20 μ	Fine Silt 20-2 μ	Clay <2μ	pH	Bulk Density Mg/m^3
0.3	22.7	21.5	25.0	30.8	7.8	1.34
0.6	21.0	16.8	27.5	34.7	7.9	1.41
0.9	26.3	18.4	25.5	29.8	8.0	1.56
1.2	33.0	15.3	25.5	26.2	8.0	1.69
1.5	47.9	15.1	18.8	18.2	8.2	1.72

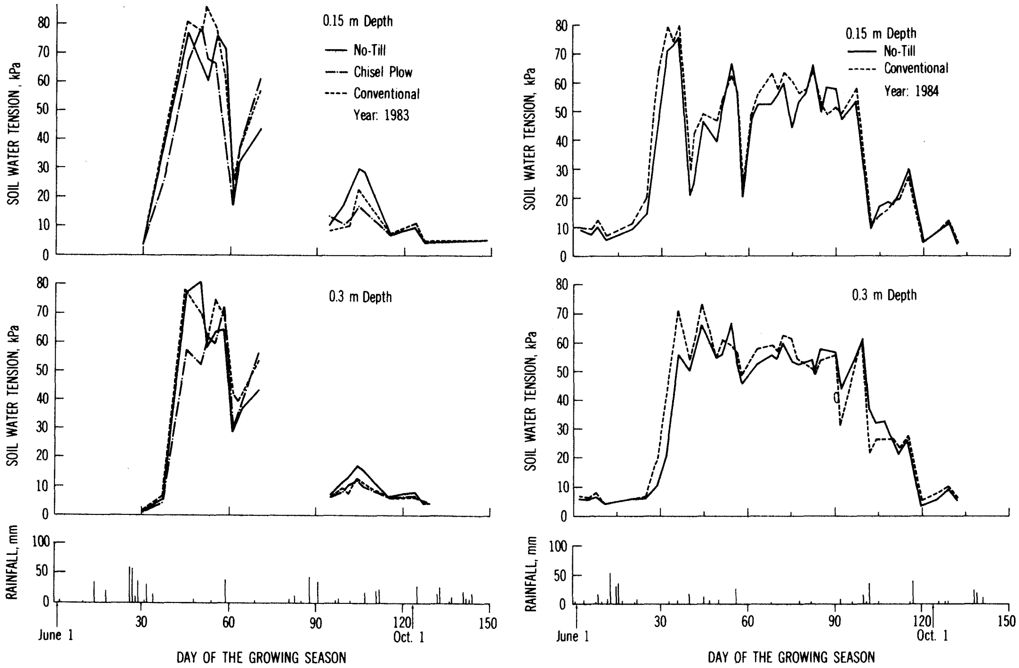

Fig. 2—Soil-water tensions as a function of time and tillage treatments at the 0.15 and 0.30 m depths during the growing seasons of 1983 and 1984.

either 32 mm or 76 mm in diameter, two or three times a month.

Soil samples were also taken for bulk density determination during the growing season. Most of the time, sample locations were selected close to the tensiometers in each treatment plot. The soil samples for bulk density determination were taken with a powered sampler, 76 mm in diameter, to a depth of 0.7 m. The soil core samples below 0.7 m depth were taken with a probe, 76 mm in diameter, in 0.15 m increments to a depth of 1.5 m, for soil bulk density determination.

The data on soil-water tensions and volumetric water contents were collected for three tillage systems (no-till, chisel plow and moldboard plow) during the 1983 and 1984 growing seasons and for the paraplow tillage system during the 1984 growing season.

RESULTS AND DISCUSSION

The rainfall observed at the experimental site during the growing seasons (April through October) of 1983 and 1984 are shown in Fig. 2. Although both years received greater than normal rainfall (total growing season rainfall was 807 mm and 891 mm for 1983 and 1984, respectively), large variations in the monthly rainfall totals were observed. In 1984, 70% of the rainfall occurred in early spring (April through June); in 1983, only 49% of the rain fell in early spring.

Figure 2 shows the average soil-water tensions at the 0.15 and 0.3 m depths for the period from June 1 to October 30 for 1983 and 1984, respectively. These figures indicate that during most of the crop growing season, no-till plots had lower soil-water tensions than the conventional tillage plots. Also, Fig. 2 shows that in 1983 chisel plow plots maintain, on the average, lower soil moisture tensions when compared with both the no-till and conventional tillage plots, but this trend does not hold during the entire growing season. A statistical analysis of the overall seasonal means of soil-water tensions at the 0.15 and 0.3 m depths for 1983 indicated that the soil tension differences between no-till, chisel plow and conventional tillage were small and statistically nonsignificant. Similar statistical analysis for 1984 data indicated that the soil-water tensions at the 0.15 m depth in chisel plow plots were significantly different from no-till, paraplow and conventional tillage treatment plots, and the soil-water tensions at the 0.3 m depth in no-till and chisel plow plots were different from other tillage treatment plots.

Figure 3 shows the average soil-water tensions as a function of soil depth and tillage practice for selected days in 1983 and 1984. The higher values of soil-water tensions (40 to 80 kPa) at 15 and 0.3 m depths during the months of June, July and August indicate that plants may experience critical moisture stress only within the top 0.3 m of the soil profile during the early and middle part of the growing season. The soil-tension data for late July and the entire month of August, 1983, show that moisture stress is possible even at the 0.6 m depth in a dry year. The lower soil-water tensions at the 0.9 m depth and below indicate that plenty of available water is present at lower depths for good plant growth. No-till and chisel-plow plots tended to maintain lower soil-water tensions to a depth of 0.9 m than the moldboard-plowed plots. Figure 3 also indicates that water use patterns by the corn roots may be about the same under various tillage systems.

Figure 4 shows the variation of soil-water content in the top 0.9 m of the soil profile for different tillage systems for selected days during 1983 and 1984. Although the no-till system of tillage tends to show more soil-water storage in the soil profile, no significant statistical difference was found between the tillage systems on the basis of two years of field data. This shows that tillage systems have little or no effect on soil-water storage in the soil profile. Also, rapid drawdown of soil-water storage has been observed for Webster silty clay

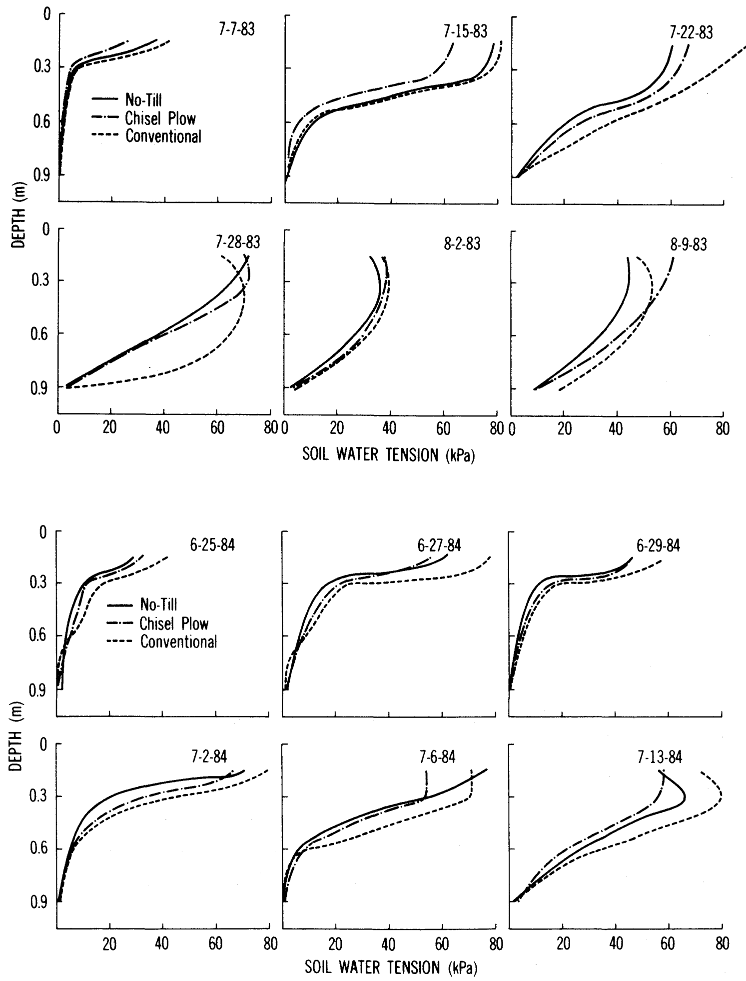

Fig. 3—Soil-water tensions as a function of depth and tillage treatments on selected days during 1983 and 1984.

loam soil. The author observed that in August 1983, during a prolonged drought (Fig. 2), soil moisture was depleted progressively with depth under all tillage systems. All water columns of the tensiometers to a depth of 0.6 m or less were broken, but corn plants had not shown much water stress. Since there was a period of about three weeks with no rainfall, indications are that corn plants used soil water from deeper soil layers for survival. This evidence suggests that once the crop roots are developed and have reached a depth of 0.9 m or deeper, tillage systems have no effect on water utilization by the plants but do affect root development (Ehlers et al., 1980).

Figure 3 shows the effect of tillage systems on soil

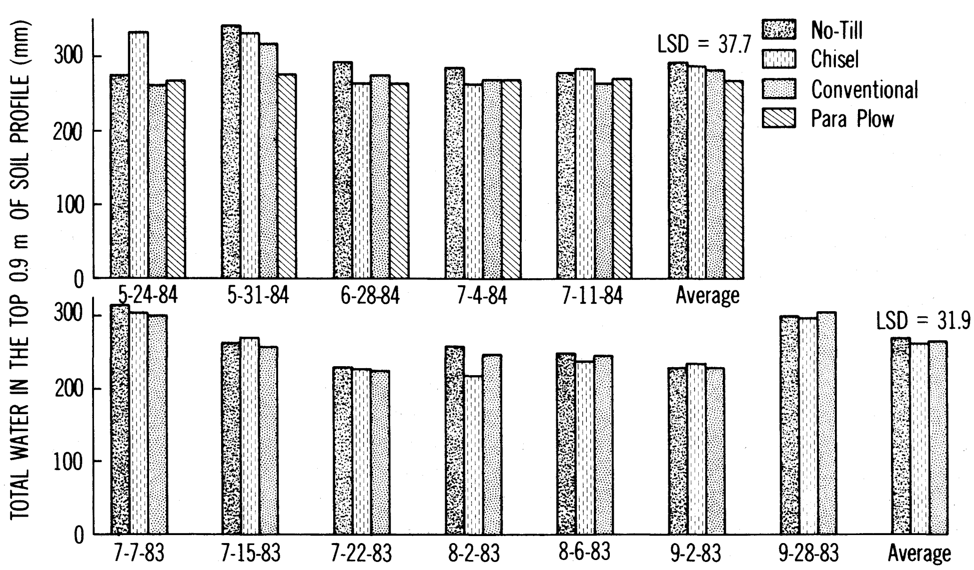

Fig. 4—Total water content in the top 0.9 m of the soil profile for different tillage systems on selected days during the growing seasons of 1983 and 1984.

TABLE 2. Effect of Tillage Systems on Crop Yields (kg/ha).

Year	Crop	No-Till	Chisel Plow	Conventional Tillage	Paraplow	$LSD_{0.05}$
1983	Corn	6113	6383	9051	7752	2687
1984	Corn	5963	7180	9490	8480	1600
Average	Corn	6038	6782	9271	8116	1399

Note: $LSD_{0.05}$ = Least significant difference at 5% level.

moisture content as a function of depth. The soil-water tensions as a function of depth and tillage directly represent the moisture status of the soil profile under various tillage systems. The average soil-water tensions in the top 0.3 m (the zone most affected by tillage) were low under no-till and chisel plow treatments when compared with conventional tillage. This shows that better soil moisture conditions in the top 0.3 m are due to the effects of no-till and chisel plow. But the moisture content differences between the tillage systems tend to be small and statistically nonsignificant.

Table 2 gives the average corn yields in the experimental plots under the four different tillage systems. Erbach et al. (1984) reported corn yields from the same tillage treatment plots. The researchers found that the variability in harvested yield was least with the chisel plow system and most with the no-till system. They also concluded that although conservation tillage systems may result in yields equal to conventional tillage systems at times, such systems could have significantly lower yields at other times. Table 2 shows that no-till treatment yielded the lowest average corn yields in comparison to the other three tillage treatments. Therefore, it is not clear if the higher soil-water storage in no-till plots is due to the no-tillage effects or if it is the result of less water uptake by the corn plants. Under drought conditions, the final yield may be limited by the amount of soil water, irrespective of the change in soil properties by tillage. On the average, the paraplow treatment yielded significantly more than the no-till and chisel plow treatments.

The variability of soil-water tension was studied by using three statistical parameters (standard deviation, coefficient of variation and range). The standard deviation (SD) and coefficient of variance (CV) were calculated as

$$SD = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n - 1}$$

$$CV = \frac{SD}{\bar{x}} \cdot 100$$

where x_i is the ith measurement of soil-water tension, $\bar{x}$ is the sample mean and n is the sample number for a given day.

Table 3 presents the overall means of the statistical parameters (standard deviation, coefficient of variation, and range—the difference between the lowest and highest values of data points) and values of least significant difference at the 5% level ($LSD_{0.5}$) of soil-water tensions as a function of depth and tillage system on a yearly basis. During this statistical analysis, we

TABLE 3. Statistics of the Soil-Water Tensions (kPa) for Different Tillage Systems as a Function of the Soil Depth for Clarion-Nicollet Webster Soil Association

Soil Depth (cm)	Statistical Parameters	1983 Tillage Systems No-Till	Conv. Till	Chisel Plow	$LSD_{0.05}$§	1984 Tillage Systems No-Till	Conv. Till	Chisel Plow	Para-Plow	$LSD_{0.05}$§
15	Mean	31.4	32.2	29.2	7.5	33.8	36.3	30.7	35.6	2.6
	SD*	22.4	41.4	35.9		18.5	18.5	15.3	22.0	
	CV†	64	99	95		51	51	51	64	
	Range	20.0	14.1	15.7		20.9	17.8	25.0	14.7	
	n‡	160	160	160		408	408	408	408	
30	Mean	27.7	28.9	25.3	4.1	33.4	35.2	31.3	36.2	1.4
	SD*	19.0	19.7	17.4		10.8	11.0	11.2	11.3	
	CV†	53	64	61		39	42	41	38	
	Range	18.0	19.3	20.5		18.0	15.8	17.6	18.0	
	n‡	160	160	160		408	408	408	408	
60	Mean	14.0	18.9	13.0	2.6	29.4	29.7	27.5	29.0	1.5
	SD*	9.9	14.4	11.0		10.3	10.1	9.7	10.7	
	CV†	81	77	126		56	59	61	56	
	Range	18.0	18.9	16.0		19.0	18.2	17.4	20.5	
	n‡	160	160	160		408	408	408	408	
90	Mean	4.8	4.6	4.1	1.4	14.0	14.3	14.5	15.2	1.6
	SD*	7.2	6.9	6.8		11.0	12.3	11.3	11.7	
	CV†	204	253	199		265	361	161	208	
	Range	8.1	9.9	8.7		20.8	25.9	22.0	24.5	
	n‡	160	160	160		408	408	408	408	
150	Mean	0.3	0.5	1.4	–	1.3	1.8	2.4	1.6	0.5
	SD*	0.0	0.0	23.1		2.7	3.6	5.1	3.0	
	CV†	0	0	965		234	356	245	321	
	Range	0.0	0.0	3.7		1.2	1.6	4.1	1.7	
	n‡	160	160	160		408	408	408	408	

* SD = Standard deviation in cm.
† CV = Coefficient of variation in percent
‡ n = Number of observations made.
§ $LSD_{0.05}$ = Least significant difference at 5% level.

found that the variability (standard deviation and range) of soil-water tension in a relatively moist soil (soil-water tensions less than 45 kPa) increases as the soil dries out at all depths and for all tillage systems. This conclusion is in agreement with the results of Webster (1966). We also found that the standard deviation of soil-water tension data started decreasing at about 45 kPa tension and continued to decrease until a tension of 80 kPa was observed. After 80 kPa, a majority of the tensiometers broke suction; therefore soil-water tension data above 80 kPa were not used in this analysis.

The statistical data given in Table 3 could be used to indicate the overall effects of tillage systems on soil-water tensions. Although the yearly means of soil-water tensions at all depths (except at 1.5 m) are lower for chisel-plow plots when compared with other tillage treatment plots, at times more variability (standard deviation and range) existed in the soil-water tension data within the same tillage system than among the four tillage systems. The overall means of standard deviation and coefficient of variation in Table 3 do not show any trend to indicate the effect of tillage systems on the statistical characteristics of soil-water tension data. The $LSD_{0.05}$ values indicate that the soil-water tension in 1984 in chisel plow plots were significantly different from other tillage treatments in the top 0.6 m of the soil profile.

CONCLUSIONS

Field experiments were conducted to determine the effects of four tillage systems on soil-water tensions and soil-water contents. This study resulted in the following conclusions:

1. On the average chisel plow plots maintained lower soil moisture tensions in the 0 to 0.3 m soil layer when compared with both the no-till and conventional tillage plots, but the differences were statistically significant only for the 1984 data and not for the 1983 data.
2. More variability in the soil-water tension data was observed within the same tillage system than among the four tillage systems. This conclusion suggests that the variability in the soil-water tension data could easily overtake the tillage-induced effects on soil-water tensions.
3. Although the no-till system tended to show more soil-water storages in the top 0.9 m of the soil profile than the other three tillage systems, the differences were not statistically significant.
4. The conventional tillage system produced the highest crop yield. The soil-water tensions had no effect on crop yields. Crop yields increased with tillage depth but best yields were obtained when tillage depth was 150 to 200 mm (for conventional tillage). Average yields for the paraplow system, with a tillage depth of about 300 mm, were about 1500 kg/ha less than the conventional tillage system.

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